



THERMAL STRESS EFFECT ON DISC BRAKE ROTOR FOR NGV VEHICLE

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**MASTER OF MECHANICAL
ENGINEERING (ENERGY
ENGINEERING)**

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**A report submitted in accordance with requirement of the Universiti Teknikal
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APPROVAL

I hereby declare that I have read this report and in my opinion this report is sufficient in terms of scope and quality as a partial fulfillment of Master of Mechanical Engineering (Energy Engineering).

Signature :

Supervisor Name :

Date :

DECLARATION

I declare that this report entitled “Thermal Stress Effect On Disc Brake Rotor For NGV Vehicle” is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

Name :

Date :

ABSTRACT

Braking system is one of the safety aspects in vehicle design that is very important to stop a vehicle safely and avoiding an imminent collision with another vehicle, person or obstacle. During braking operation, most of the kinetic energy is converted into thermal energy and thus increases the disc temperature. Excessive temperature with poor heat dissipation would causes problems such as cracking, coning and brake pad failure. Therefore it is important to have sound knowledge on temperature distribution and thermal stress so that the designed brake will fully function. This study was conducted with a focus on the effect of thermal stress and temperature distribution behaviour on ventilated disc brake with various loading of the NGV vehicle. Steady state and transient response are used to predict the temperature distribution, deformation as well as stresses during the worst and extreme braking condition. Finite element analysis approached is conducted to identify the temperature distributions and behaviours of disc brake rotor in steady state and transient response. ANSYS software is used to perform the thermal analysis and predict the temperature distributions and behaviours at various loads. Results from both steady state and transient response are compared so that the result will assist the automotive industry in developing optimum and effective disc brake rotor.

ABSTRAK

Sistem brek merupakan salah satu daripada aspek keselamatan dalam reka bentuk kenderaan yang sangat penting untuk menghentikan kenderaan dengan selamat dan mengelakkan dari berlakunya pelanggaran dengan kenderaan lain, orang atau halangan. Semasa operasi membrek, kebanyakan tenaga kinetik ditukar kepada tenaga haba dan dengan itu meningkatkan suhu cakera. Suhu yang berlebihan dengan pelepasan haba yang lemah akan menyebabkan masalah seperti keretakan, perubahan bentuk kepada kon dan kegagalan pad brek. Oleh itu adalah penting untuk mempunyai pengetahuan luas tentang taburan suhu dan tegasan haba supaya brek yang direka dapat berfungsi sepenuhnya. Kajian ini dijalankan dengan memberi tumpuan kepada kesan tingkah laku tekanan dan taburan suhu haba ke atas cakera brek berongga dengan pelbagai bebanan terhadap kenderaan jenis NGV. Tindakbalas keadaan mantap dan keadaan berubah dengan masa digunakan untuk meramal taburan suhu, perubahan bentuk dan juga tegasan semasa keadaan membrek yang paling teruk dan melampau. Langkah analisis unsur terhingga dijalankan untuk mengenal pasti taburan suhu dan tingkah laku cakera brek dalam tindakbalas keadaan mantap dan keadaan berubah dengan masa. Perisian ANSYS digunakan untuk melaksanakan analisis terma dan meramalkan taburan suhu dan tingkah laku pada pelbagai beban. Keputusan daripada kedua-dua tindakbalas keadaan mantap dan keadaan berubah dengan masa dibandingkan supaya hasilnya akan membantu industri automotif dalam membangunkan cakera brek yang optimum dan berkesan.

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LIST OF SYMBOLS

| | | |
|--------------------|---|--|
| \dot{q} | – | Heat Flux (W/m ²) |
| \dot{Q} | – | Heat Transferred per Unit Time is (J/s or Watt, W) |
| Q | – | Thermal Energy (Joule, J) |
| ΔT | – | Average temperature increase per stop (°C) |
| \dot{Q}_{cond} | – | Conduction Heat Transfer (kW) |
| \dot{Q}_{conv} | – | Convection Heat Transfer (kW) |
| \dot{Q}_{emit} | – | Radiation Heat Transfer (kW) |
| (Al-MMC) | – | Aluminium Metal Matrix Composite |
| (CH ₄) | – | Methane |
| (DBA) | – | Disc Brake Australia |
| [C] | – | Thermal capacitance matrix |
| [K] | – | Stiffness Matrix |
| $\{\dot{T}\}$ | – | Vector of nodal rates of temperature increases |
| $\{F\}$ | – | Nodal Forces |
| $\{T\}$ | – | Thermal Condition Containing Temperature |
| $\{\delta\}$ | – | Resultant Nodal Displacement |
| μ | – | Dynamic Viscosity of air (1.872 x 10 ⁻⁵ kg/m.s) |
| μ_p | – | Friction coefficient of brake pad and disc surface |
| μ_R | – | Coefficient of friction of dry tarmac, gritted bitumen |
| A | – | Area (m ²) |
| A_{sect} | – | Cross sectional area normal to the direction of heat transfer (m ²). |
| A_p | – | Pad area (m ²) |
| A_{bs} | – | Area of both sides (m ²) |
| A_R | – | Rotor surface area (m ²) |

| | | |
|---------------|---|--|
| $Area_{in}$ | – | Inner radius area of disc brake |
| $Area_{out}$ | – | Outer radius area of disc brake |
| A_s | – | Surface area of object (m^2) |
| A_s | – | Surface area through which convection heat transfer occurs (m^2) |
| BCIRA | – | British Cast Iron Research Association |
| CAD | – | Computer Aided Design |
| CFD | – | Computational Fluid Dynamic |
| CG | – | Centre Gravity (mm) |
| CGH | – | Centre Gravity Height (mm) |
| CMM | – | Coordinate Measuring Machine |
| CNG | – | Compressed Natural Gas |
| C_p | – | Specific heat capacity, (J/kg.K) |
| c_R | – | Specific heat grey cast iron (J/kg.°C) |
| d_h | – | Hydraulic diameter (m) |
| D_i | – | Inner diameter (m) |
| D_o | – | Outer diameter (m) |
| DR | – | Deceleration of normal passenger |
| E | – | Young's modulus, (Gpa) |
| ε | – | Emissivity ($0 \leq \varepsilon \leq 1$) |
| F | – | Force on each pad (N) |
| F_{BF} | – | Braking force at front tyre |
| F_{BR} | – | Brake force from pad friction (N) |
| FEA | – | Finite element analysis |
| FEM | – | Finite Element Method |
| FKM | – | Fakulti Kejuruteraan Mekanikal |
| GW | – | Gross Weight |
| h | – | Convection Heat Transfer Coefficient, in $W/m^2.K$ |
| h_c | – | Convection heat transfer coefficient of disc brake (W/m^2K) |
| h_R | – | Heat transfer coefficient of rotor surface (W/m^2K) |
| IGES | – | Initial Graphics Exchange Specification |
| k | – | Thermal conductivity, ($W/m^{\circ}C$) |
| k | – | Thermal Conductivity, watt per meter per Kelvin (W/mK). |
| k_a | – | Thermal conductivity of air ($W/m.K$) |
| L | – | Vane length (m) |

| | | |
|----------------|---|---|
| L | – | Length (mm) |
| L | – | Wheelbase of the car |
| LNG | – | Liquefied Natural Gas |
| m_c | – | Gross mass of vehicle |
| M_F | – | Moment of equilibrium |
| m_R | – | Mass of rotor (kg) |
| N_{disc} | – | Angular velocity of the tyre (rpm) |
| NGV | – | Natural Gas Vehicle |
| NU_D | – | Nusselt Number of disc brake |
| p | – | Pressure (Pa) |
| P_{ave} | – | Average pad pressure applied on disc surface (MPa) |
| A_p | – | Brake pad area (m ²) |
| P_B | – | Braking Power (W) |
| Pr | – | Prandtl number |
| $q_{inboard}$ | – | Heat flux generated on the inboard surfaces (W/m ²) |
| $q_{outboard}$ | – | Heat flux generated on the outboard surfaces (W/m ²) |
| r | – | Mean radius (from centre wheel to centre pad) (m) |
| r_0 | – | Outer radius of disc (m) |
| R_{ave} | – | Radius of average vane ring (m) |
| r_c | – | Radius of disc centroid/mean radius from centre wheel to centre pad (m) |
| Re | – | Reynolds number of disc braking surface |
| R_F | – | Reaction force at front |
| R_F | – | Force reaction on front tyres |
| R_R | – | Reaction force at rear |
| r_t | – | Radius of tyre |
| r_{tyre} | – | Radius of 185/60R14 tyre (mm) |
| r_{tyre} | – | Radius of tyre (288.29 mm, Size of tyre :185/60R14) |
| R_{vi} | – | Radius of vane inner ring (m) |
| R_{vo} | – | Radius of vane outer ring (m) |
| S_{ave} | – | Average ring chord length (m) |
| SG | – | Ductile iron |
| S_{in} | – | Inner ring chord length (m) |
| S_{out} | – | Outer ring chord length (m) |

| | | |
|---------------|---|---|
| S_{total} | – | Total Distance |
| T | – | Braking torque (Nm) |
| T | – | Temperature difference between two surfaces separated by distance Δx (K/°C) |
| T_{∞} | – | Ambient temperature (°C) |
| T_{∞} | – | Ambient temperature (K/°C) |
| $T_{braking}$ | – | Brake torque |
| t_C | – | Cooling time cycle (s) |
| T_s | – | Braking Time |
| t_S | – | Brake time (6s) |
| T_s | – | Surface temperature (K/°C) |
| T_s | – | Surface temperature of object (K/°C) |
| T_{tyre} | – | Tyre torque |
| UK | – | United Kingdom |
| $V_{air-ave}$ | – | Average air velocity (m/s) |
| V_{air-in} | – | Velocity of air flow through the inlet of inner vane passage (m/s) |
| $V_{air-out}$ | – | Velocity of air flow through the outlet of inner vane passage (m/s) |
| v_R | – | Rotor volume (m ³) |
| V_{tr} | – | Travel Speed |
| $V_{vehicle}$ | – | Velocity of normal passenger (m/s) |
| WB | – | Wheelbase (mm) |
| $Weight_R$ | – | Weight distribution of vehicle at rear axle |
| WT | – | Weight transfer |
| WT_{Front} | – | Weight transfer at front tyre |
| W_{total} | – | Total weight of car |
| Δh | – | Height of rear axle when rise |
| ΔW_f | – | Front tyre weight reading on scale during test |
| Δx | – | Wall Thickness (m) |
| θ | – | Fraction angle (°) |
| μ | – | Coefficient of friction |
| ν_a | – | Kinematic viscosity of air (m ² /s) |
| ρ | – | Density, (kg/m ³) |
| ρ_R | – | Rotor density (kg/m ³) |
| σ | – | Stefan-Boltzman constant (5.670 x 10 ⁻⁸ W/m ² .K ⁴) |

| | | |
|-----------------|---|--|
| ω_{disc} | – | Angular velocity of the disc (rad^{-1}) |
| ω_{tyre} | – | Angular velocity of the tyre (rad^{-1}) |